TRENDS IN LANGLEY HELICOPTER NOISE RESEARCH

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INTRODUCTION

This paper presents a broad perspective of needs in helicopter exterior and interior noise control and contains descriptions of the Langley program and facilities in the related technology areas. Emphases are given to those items which support noise certification of civil helicopters and which result in reduced environmental noise impact to community residents as well as to helicopter passengers. The activities described herein are related to the Langley responsibilities for helicopter acoustics as defined by NASA roles and missions.

PROGRAM GOALS

The main goal of the Langley program is to develop a broad base of improved noise and noise-induced vibration control technology. Anticipated outputs from the program are indicated at the bottom of figure 1. They include the ability to design helicopters to comply with noise regulations, as well as the increased passenger and community acceptance.

Parallel thrusts are underway as indicated in figure 2 in the design and operations and the human factors related areas. The so-called physical acoustics portions of the program include the development of various categories of helicopter noise reduction information and also the development and validation of prediction methods. The human factors activities, on the other hand, are aimed at a fuller understanding of the effects of helicopter noise on people. The identification of valid noise quantification units, and the development of acceptance criteria, are included as part of a general understanding of the response of people to combined noise and vibration environments. Also implied is an understanding of the significance of operational procedures as a means for controlling community noise responses and thus minimizing the resulting environmental impacts.

ELEMENTS OF LANGLEY PROGRAM

The main elements of the Langley helicopter acoustics program, in both the physical acoustics and psychoacoustics areas, are listed as follows:

<u>Source noise control</u>

Farassat theory and refinements
Parametric sensitivity studies (experimental and theoretical)
Evaluation of active and passive rotor tips
Main rotor/tail rotor interactions

Operational factors
- Noise footprint definition

Prediction
- Noise prediction module development
- Flight test validation
- Establishment of data bank

Community acceptance
- Laboratory subjective tests
- Laboratory/field tests (Wallops Flight Center)
  - Flyover human jury tests
  - Indoor/outdoor effects tests
- Community response tests

Passenger acceptance
- Laboratory simulation
- Field flight tests

A number of specific projects are identified in source noise control, prediction, operational factors, community noise, and interior noise. Although the listing is not necessarily complete, those included are meant to suggest the nature and scope of the current research program. Also included in this material are indications of the research tools and methods to be brought to bear on particular types of problems.

Source Noise Control

The Farassat theory for rotor noise is a potentially powerful tool for basic rotor noise sensitivity studies over a wide range of rotor tip speeds and loading conditions (see ref. 1). The immediate problem is to establish credibility in this and any other similar theoretical methods that may become available. The plan is to make a few critical checks for current helicopters. This involves the ingredients identified in figure 3. The inputs to the computer program include details of the rotor geometry and its flight conditions along with details of its spanwise and chordwise blade loading time history. The above information is needed for cases for which flyover noise information is also available. The output of the computer program is a time history instantaneous pressure p which can in turn be resolved into frequency spectra and noise level time histories. Measured and calculated noise signatures will be compared for one or more helicopter configurations, for which appropriate input data are available. Anticipated results include the identification of operating ranges for which the theory is acceptable along with some indications of the areas in which refinements may be required.

Once the theoretical methods have been validated by wind tunnel and flight test results, the plan is to exercise them in parametric theoretical studies in which the effects of systematic changes in the input variables are evaluated in terms of the rotor noise output. These data will be directly useful in establishing the sensitivity of the rotor noise to any of several possible changes in geometry and operating conditions.

One of the demonstrated approaches to control of rotor noise is by means of the alteration of the blade tip vortex structure and the manner in which it subsequently interacts with the aerodynamic flow environments of the following blades. The blade tip flow fields have in the past been helpfully altered by means of blade tip geometry changes and by air mass injection at the tips (see refs. 2 and 3). In order to try to answer some questions about the basic source mechanisms and the relative changes in aeroacoustic performance due to such tip modifications, further experiments are planned in both the University of Maryland (under contract) and the Langley V/STOL wind tunnels (see fig. 4). In the University of Maryland studies, the aeroacoustic performance of both active and passive tips will be compared on blade models of the same diameter and over the same range of operating conditions. The V/STOL tunnel tests will be accomplished with the general research rotor system model (see ref. 4). A standard blade will be run over a range of forward flight and descent conditions to map out the conditions under which banging is encountered. Then subsequent tests will evaluate the effectiveness of the various tip shapes in the figure to alleviate blade banging.

Another well-recognized noise producing phenomenon is the interaction of the tail rotor with the downwash flow field from the main rotor (see ref. 5). As indicated in the sketch of figure 5, the tail rotor may be totally or partially immersed in the main rotor flow field and in some cases may encounter periodic disturbances associated with the tip vortex structure of the main rotor. Further parametric studies in a quiet wind tunnel are planned with a variable geometry main rotor/tail rotor model to evaluate systematically the effects of such variables as main rotor/tail rotor relative position, direction and speed of rotation, number of blades and blade planform (including sweep) on the tail rotor noise. Attempts will also be made to characterize the inflow to the tail rotor for a range of operational conditions as the basis for identification of optimum tail rotor aeroacoustic configurations.

Operational Factors

Recent measurements of helicopter in-flight noise signatures have indicated that the ground exposures are closely related to the manner in which the helicopter is operated (see ref. 6). Figure 6 illustrates the level flight ground noise patterns for two different helicopters one of which operates in a banging mode. The two associated noise contours differ in shape. The nonbanging rotor tends to have a radiation pattern such that the most intense noise is directed downward and the constant noise level contour is essentially symmetrical about the ground track. The banging rotor, on the other hand, apparently has a radiation pattern such that the most intense noise radiates in or near the plane of the rotor disk and is skewed left with respect to the flight direction. For operation in built-up areas a good appreciation of the sizes and shapes of these ground noise contours is essential for minimizing the community noise impacts. Further measurements of the type illustrated in figure 6 are planned for other operating conditions using the ROMAAR facility at NASA Wallops Flight Center.

Noise Prediction

One of the greatest needs of the helicopter designer in order to meet specified noise requirements is the availability of good engineering methods for flyover noise prediction. These are largely empirical at the present time and tend to be configuration sensitive. Consequently, there is an urgent need for analytically based methods valid for a range of configurations and operating conditions.

A proposed approach to an analytical prediction method is illustrated in the schematic diagram of figure 7. The noise critical inputs include detailed information on the configuration, its operating conditions and the rotor load distribution. The prediction program then calculates noise from the rotor system and the other noise generating components of the helicopter and sums them up. The overall noise is then propagated to the ground level observer location through a stratified atmosphere. A series of such calculations will produce a flyover noise time history in arbitrary evaluation units (see ref. 7).

Once a validated procedure is available, two quite different applications are planned. One is a series of sensitivity studies involving theoretical calculations in which the inputs are varied parametrically to evaluate their effects on the noise radiation field. The results of such calculations will form a data bank for evaluating future designs. Another planned application of the prediction methods is illustrated in figure 8.

Assuming that the computerized prediction method properly accounts for the configuration and operating conditions of the particular helicopter in question, it can then be coupled to the input of a noise synthesizer (see ref. 8). The synthesizer translates the computer program into audio signals which represent the noise from a particular helicopter operation. These audio signals can then be used to expose a jury of test subjects to helicopter noises for subjective evaluation. This is a tool for identifying those features of the noise signature which are most annoying and then relating them back to particular features of the helicopter design and/or operations. This offers the possibility of optimizing the acoustic signature of a helicopter in its early design stage.

Community Acceptance

Community response to the unique noise signatures and operating characteristics of helicopters is important to their development and utilization. Closely related to this issue is the development of procedures in support of certification of helicopters with respect to noise, as previously discussed. The Langley approach to research in the area of human response involves controlled laboratory studies, controlled flyover tests, and commmunity repsonse surveys.

Some of the laboratory simulation facilities available for human response studies are shown in the photographs of figure 9(a). They consist of an Exterior Effects Room (EER) and an Interior Effects Room (IER). The EER is an auditoriumlike room having a multichannel audio system capable of reproducing noise signatures which properly represent the direction and movement of the source. The IER is configured as a living room in a house and is used for obtaining the subjective response to noise signatures as they would be heard indoors. In addition, vibration exciters are available to simulate noise-induced vibrations associated with helicopter overflights.

Examples of helicopter-related experiments which have recently been performed in these simulation facilities are illustrated in figure 9(b). The EER has been used to examine the effects of several characteristics of helicopter blade-slap noise as described in reference 9. Blade-slap noise was simulated by superimposing impulsive noises on broadband background noise. Variables included: the number of sine waves in a single impulse; the frequency of the sine waves; the impulse repetition frequency; the sound pressure level (SPL) of the continuous noise; and the idealized crest factor of the impulses. Analysis of the subjective data indicated that each of the five parameters had a statistically significant effect upon the annoyance judgments. Detailed results are presented in references 9 and 10.

A sketch of the IER test set up to evaluate both flyover noise and noise-induced vibration is illustrated at the bottom of the figure along with an example of expected results. Subjects are simultaneously exposed to noise and various levels of building vibrations. Of particular concern is whether the associated vibrations are detectable and, if so, are they an important consideration in community response to helicopter operations (see ref. 11). The laboratory study is being guided by an analysis of the vibration levels recorded during recent helicopter noise tests conducted at the Wallops facility.

This latter study was conducted at Wallops to provide information on the relative importance of the impulsive characteristics of helicopter noise to human response. The design of the experiment is shown schematically in figure 9(c) and scenes of the test are shown in the photograph of figure 9(d). Subjects were located in each of the three test areas situated in a straight line parallel to the flight paths. The primary subject groups were located out of doors and made judgments of the overflights. A second and third group made judgments, respectively, where both interior noise and house vibrations were recorded. Four level flight paths were used as shown in the figure for the helicopters and a fixed-wing reference aircraft.

The data from this experiment are being analyzed to determine whether an impulsiveness correction to the proposed certification noise measure, EPNdB, is necessary to adequately predict the annoyance of helicopter noise. The necessity for and magnitude of such a correction will be indicated if the results of the experiment are separable in terms of some measures of impulsiveness as indicated in the right-hand sketch of the figure.

A related program has recently been initiated under contract to study the reactions of people in communities highly impacted by helicopter noise. The program is designed to determine whether a significant difference exits in the percent of a population highly annoyed by a noise environment uniformly composed of many sources and one with a noise environment containing a high proportion of helicopter noise. If a significant difference in the percent highly annoyed is detected, a helicopter "penalty factor" will be developed which can be used to adjust aircraft noise metrics upward to account for the increased attitudinal response to helicopter noise. The program will consist of both a telephone survey of social attitudes and a field noise measurement survey in two communities to be selected - one subjected to high helicopter noise impact, and one similar in all respects except for an absence of helicopter noise. A computerized multivariate regression analysis will combine the social and physical data to distinguish the difference in the proportion highly annoyed that is attributable to helicopter noise, and from this, the "penalty factor" will be determined, based on established relationships between community noise exposure and expected degrees of annoyance.

Passenger Acceptance

The interior environment of current and future helicopters is important to the ride quality and passenger acceptance of these vehicles. To fully evaluate the influence of the interior noise (and vibration) on passenger acceptance, the vehicle noise environment as well as the response of passengers to this type of stimulus must be understood. Such an understanding of the environment and its effects is essential to the development of cost effective interior noise control technology.

Passenger or subjective response to noise and vibration is being studied both in the laboratory and in the field. In general, the laboratory studies examine the details of the environmental stimuli which cause adverse response whereas the field studies concentrate on understanding the integrated effect of noise and other environmental factors on passenger acceptability.

The ongoing ride quality program being conducted at Langley Research Center (ref. 12) utilizes the three-degree-of-freedom motion simulator shown in the photograph of figure 10(a). The simulator is configured to represent the interior of an aircraft and can be fitted with four first-class seats (as illustrated) or with six tourist-class seats. The simulator is driven by hydraulic actuators which provide motion in the vertical, lateral, and roll direction. Single- or multiple-axis inputs can be obtained by oscillators or actual field-recorded tapes over a frequency of 0 to 30 Hz and an amplitude of up to $0.5\ g_{peak}$.

The ongoing studies are directed toward the development of a ride quality model which includes the effects of both multifrequency and multiaxis vibratory inputs, as well as noise. The approach being followed consists of the development of "equal vibration discomfort curves" as a function of level and frequency for each axis of vibration, and determination of within-axis and between-axis masking, and the interaction of vibration and noises.

Example results of this program are summarized in the chart of the figure where successive constant discomfort curves (DISC curves) ranging from 1 to 7 are presented in terms of the A-weighted sound pressure level and the rms vibration acceleration level in g units. A DISC of 1 is approximately the discomfort threshold whereas a DISC of 7 would be relatively uncomfortable. Results suggest that human response is highly dependent upon both noise and vibration, and furthermore, the degree of dependence is related to the level of the stimuli. For example, at high noise levels, the vibration influence is relatively small in comparison to the influence at low levels of interior noise. Current studies are being directed toward quantifying the response to these combined stimuli over a wide range of conditions and incorporating the results into a user oriented ride quality model.

On a comparative basis, the range of interior noise levels of helicopters is generally higher than that for conventional aircraft and surface vehicles, as indicated in the upper chart in figure 10(b). In order to evaluate the environment and passenger acceptance of large helicopter airliners, a modified version of the CH-53 military transport helicopter has been flight tested. A photograph of the helicopter, the modified cabin, and the results of a study to evaluate the effectiveness of various interior treatments are shown in the figure.

Interior noise levels in the untreated (military) helicopter were approximately 110 dB(A). The acoustic treatment reduced these levels to 90dB(A) inside the passenger cabin, but results of questionnaires indicated that this was not satisfactory. The primary source of interior noise in the treated cabin was found to be gear clash in the main gearbox. A reduction of this gear clash noise by 12 dB would result in interior noise levels which are comparable to current narrow-body jet transports during cruise (ref. 13). Research into the fundamentals of gear noise control at the source and methods of mechanical isolation of the gearbox are obviously needed to control gear noise.

CONCLUDING REMARKS

An attempt has been made to characterize the Langley Research Center program in helicopter acoustics and to identify future trends wherever possible. The main thrusts in physical acoustics are noted to be in rotor noise generation and control and in the development of engineering prediction methods. Emphasis is on the development of theoretical methods in conjunction with parametric model tests in quiet wind tunnels.

Community and passenger acceptance studies involve the application of some unique laboratory facilities as well as field investigations to define and quantify characteristics of helicopter stimuli affecting human response. The results provide criteria and design guidelines for reduction of community noise as well as the noise and vibration transmitted into the passenger cabin.

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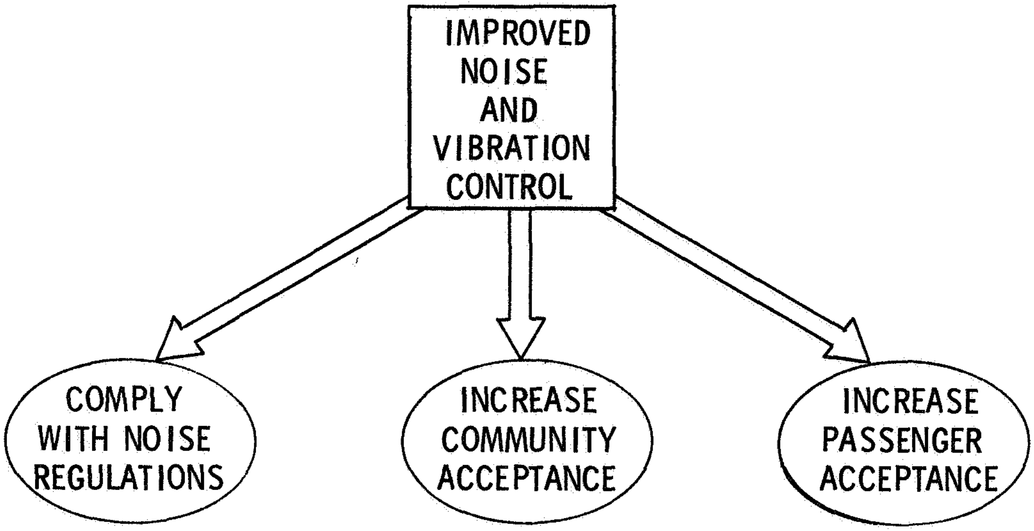


Figure 1.- Goal of Langley programs.

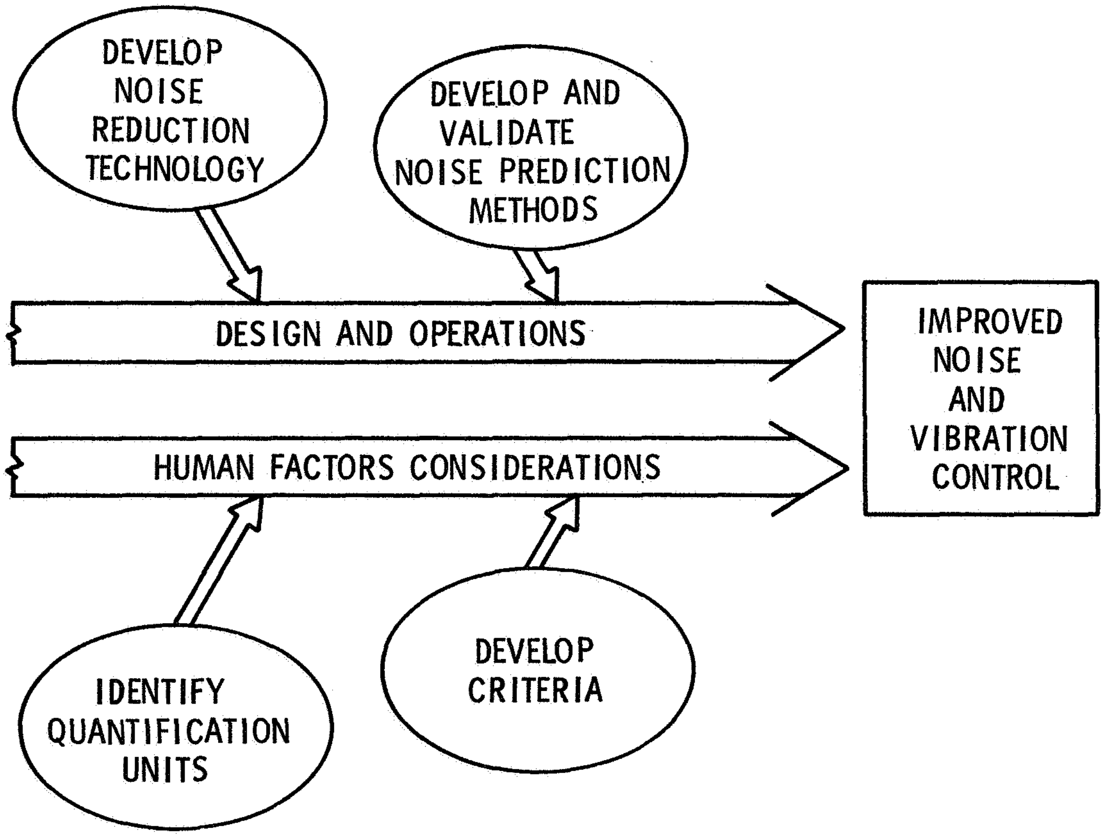


Figure 2.- Thrust of Langley program.

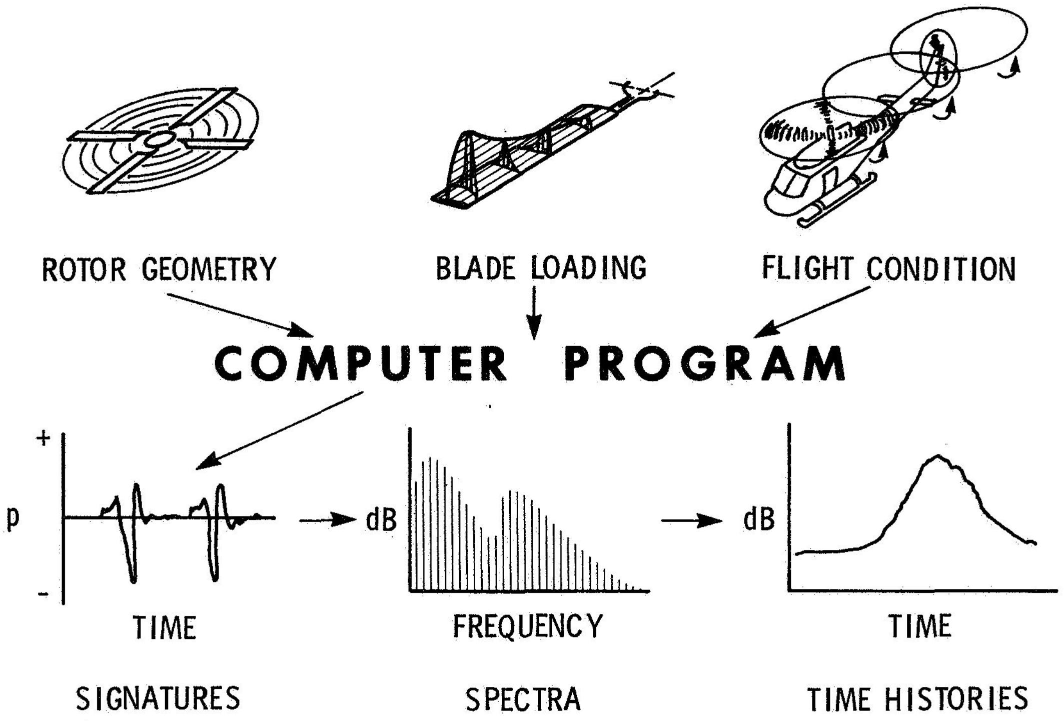


Figure 3.- Farassat rotor noise theory.

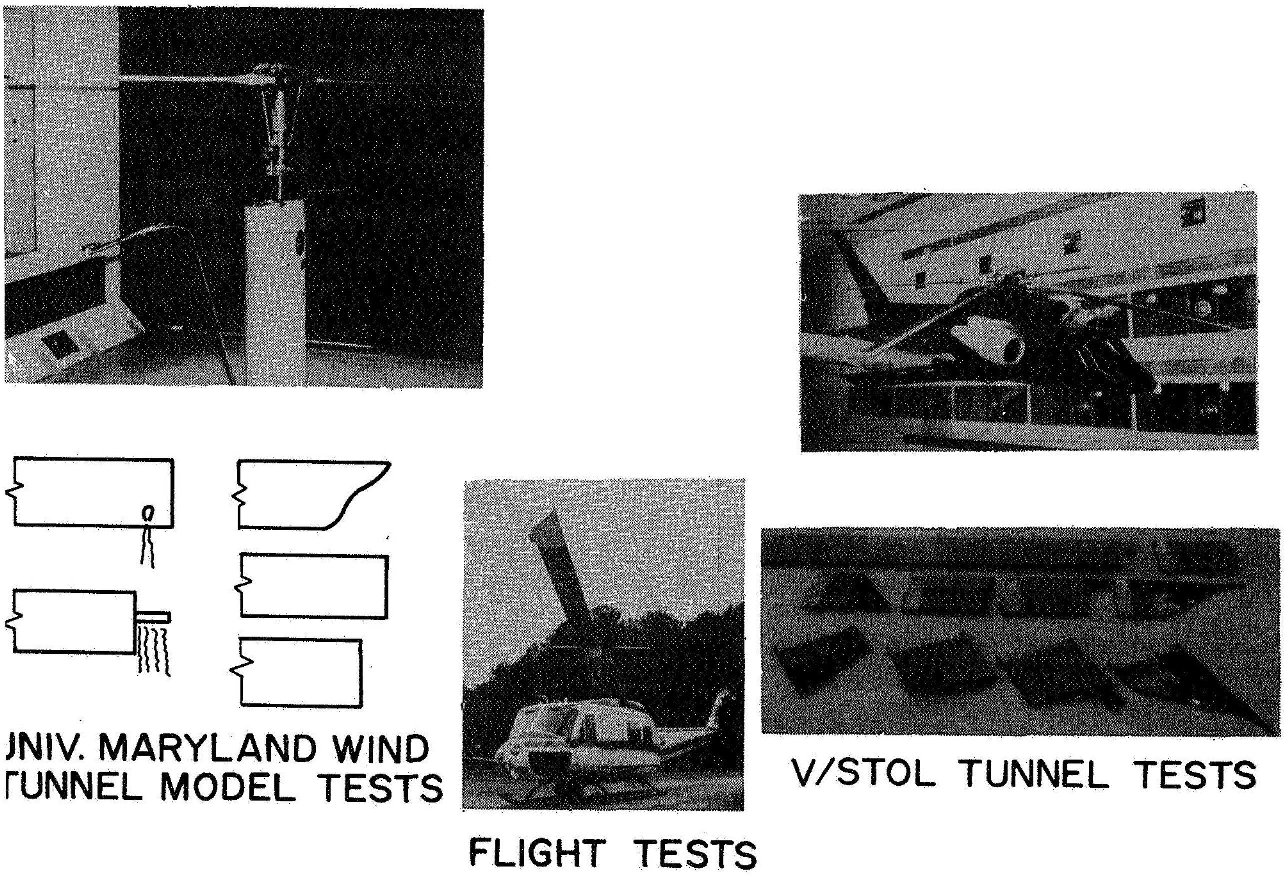


Figure 4.- Tip vortex modifications.

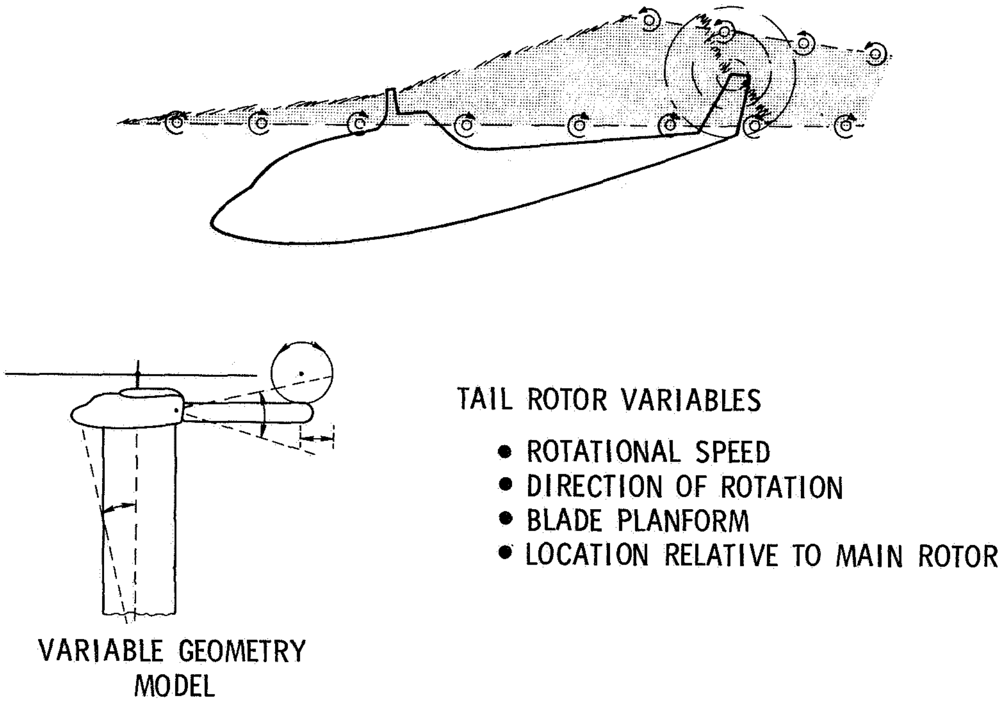


Figure 5.- Anechoic wind tunnel tests of main rotor/tail rotor interaction noise.

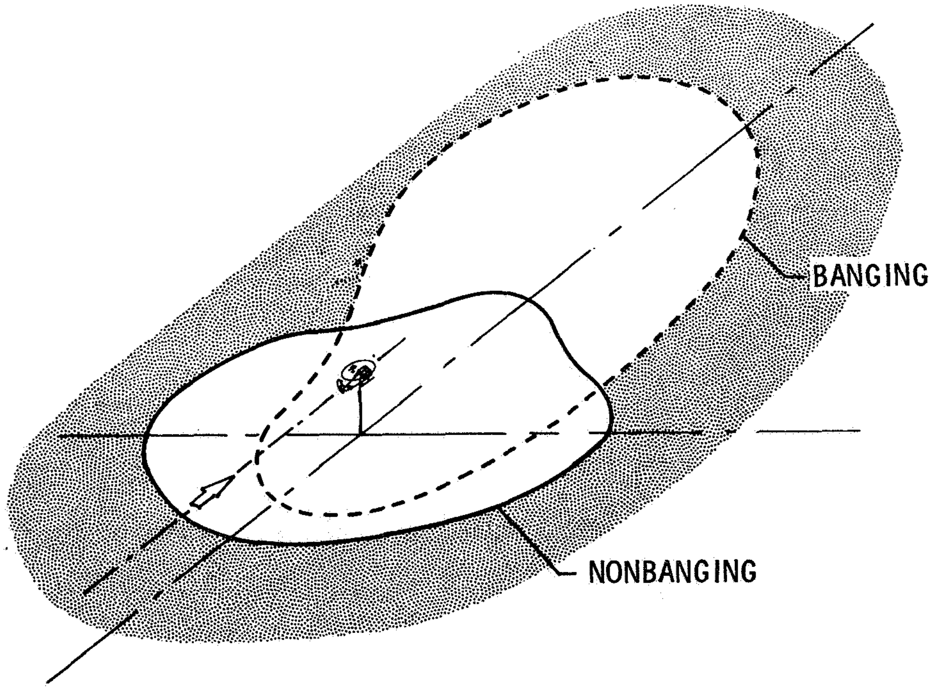


Figure 6.- Level flight dB(A) ground noise patterns.

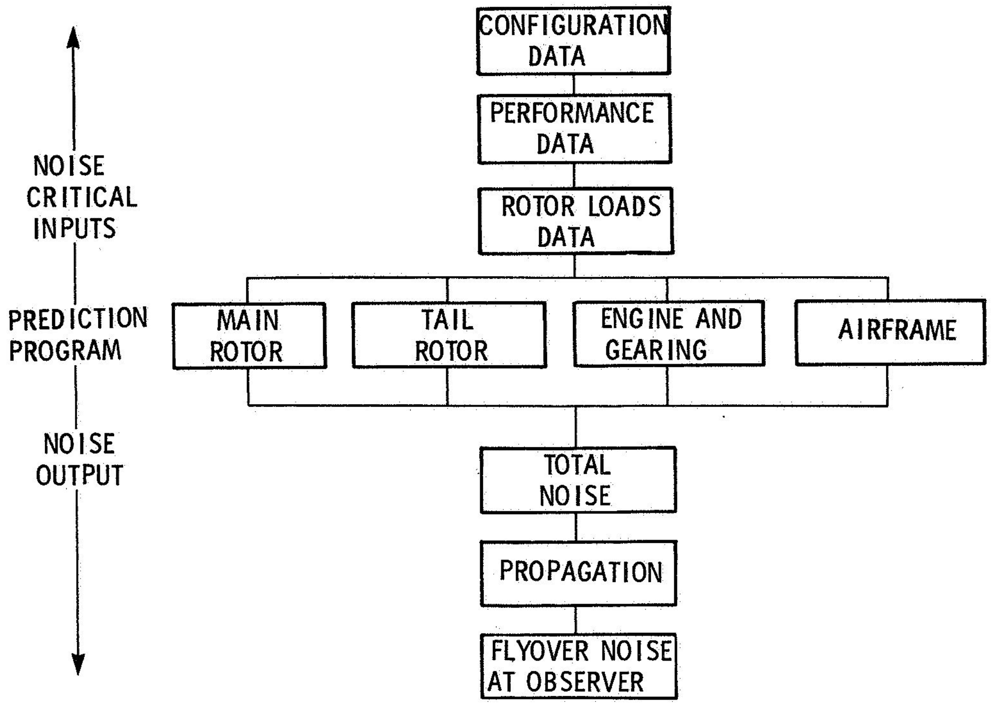


Figure 7.- Helicopter noise prediction.

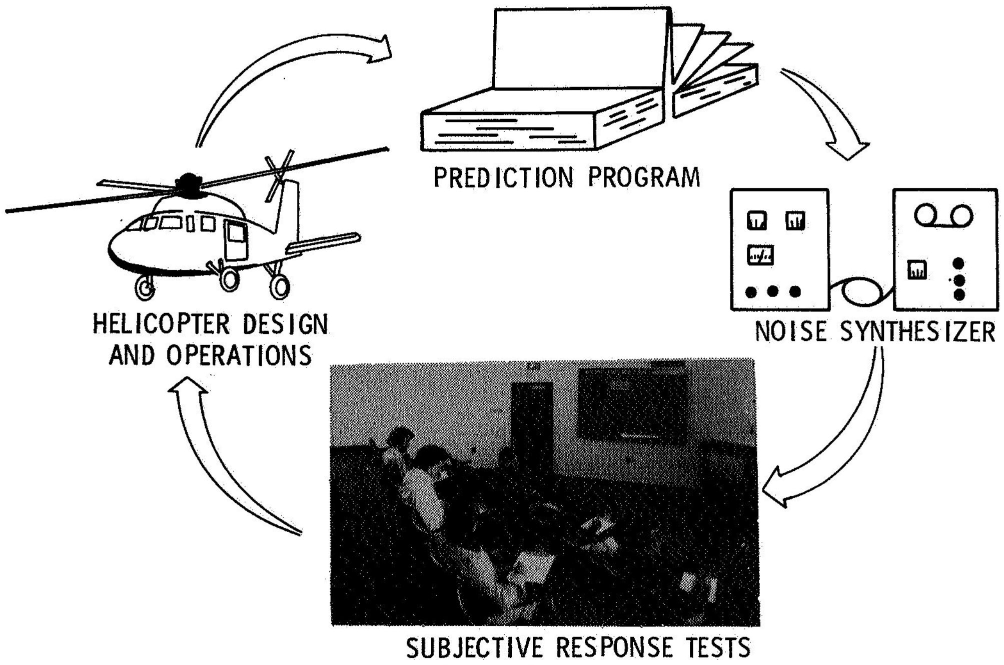
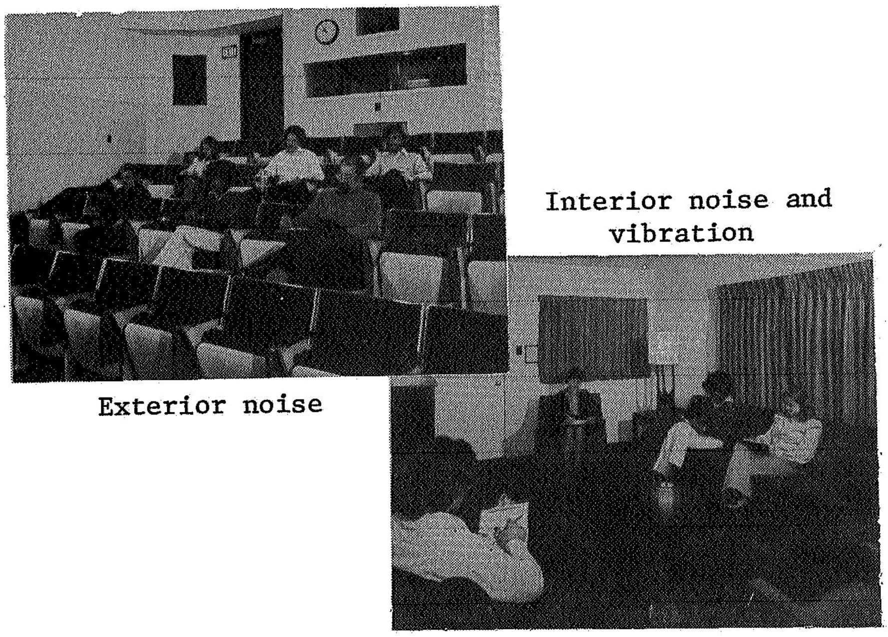
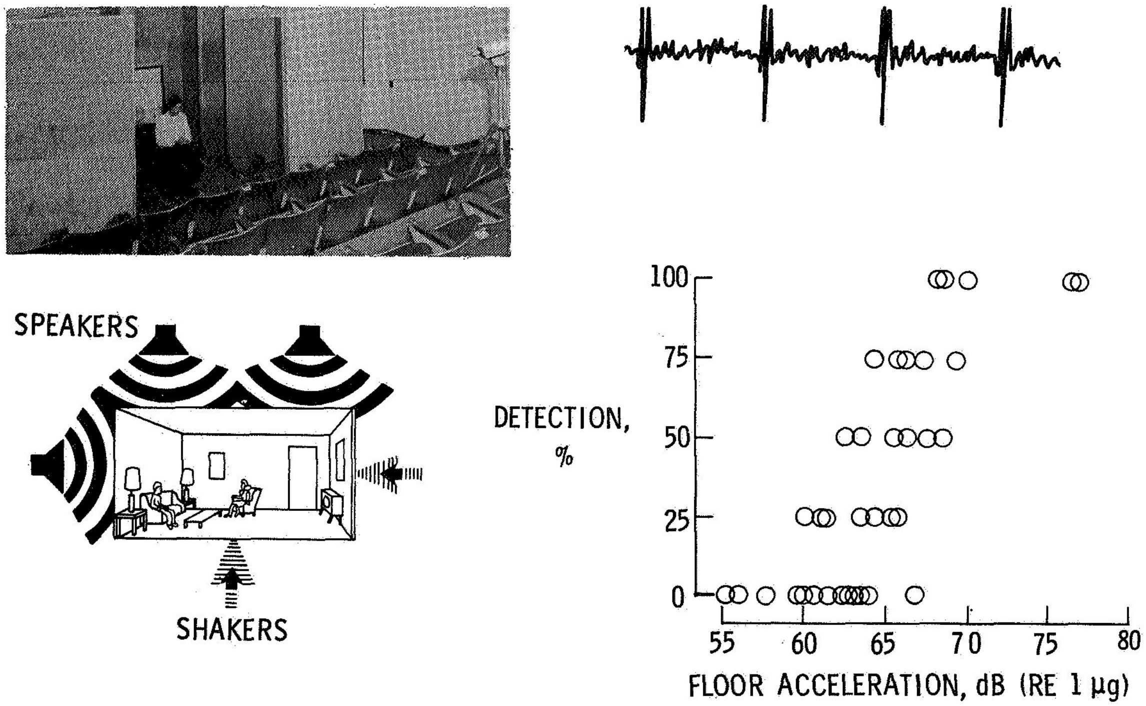


Figure 8.- Helicopter noise synthesis.

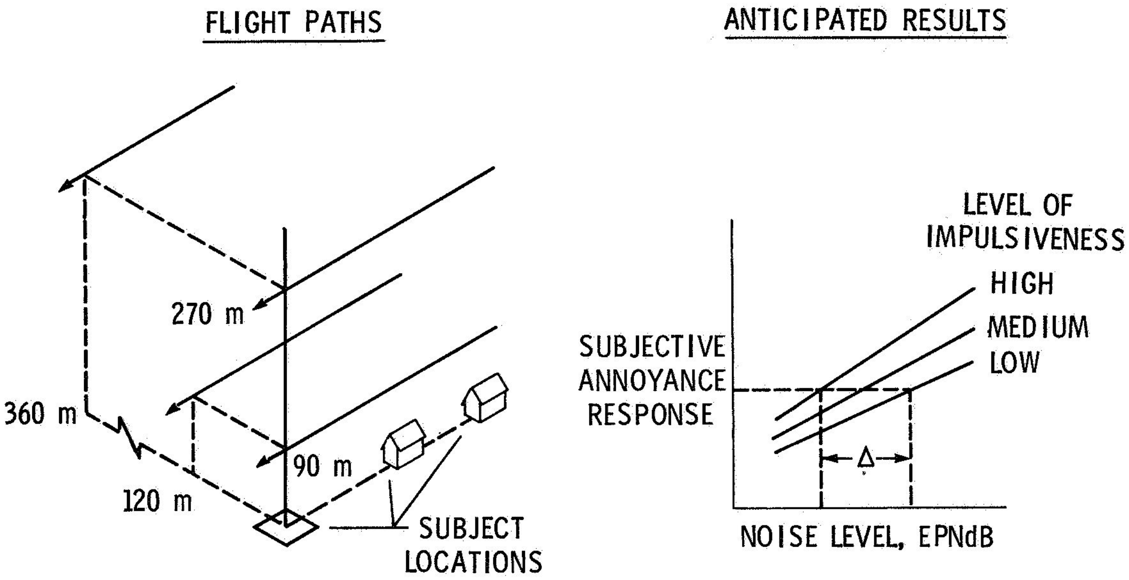


(a) Laboratory simulation facilities.

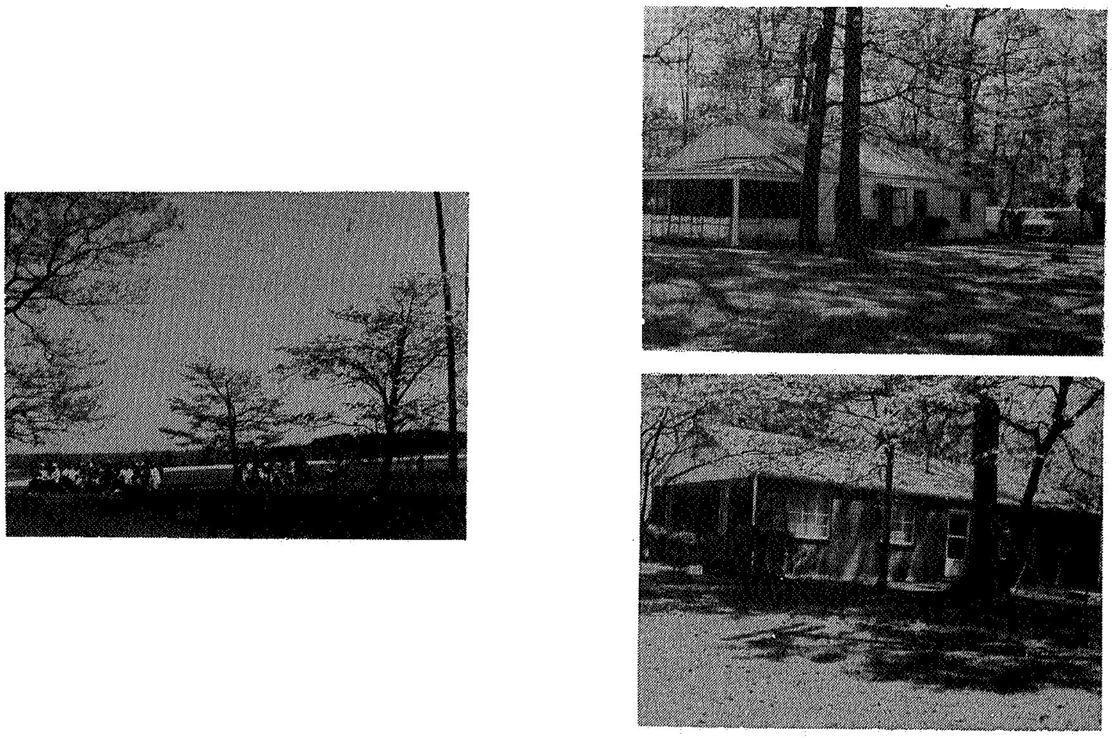


(b) Laboratory research results.

Figure 9.- Community acceptance.

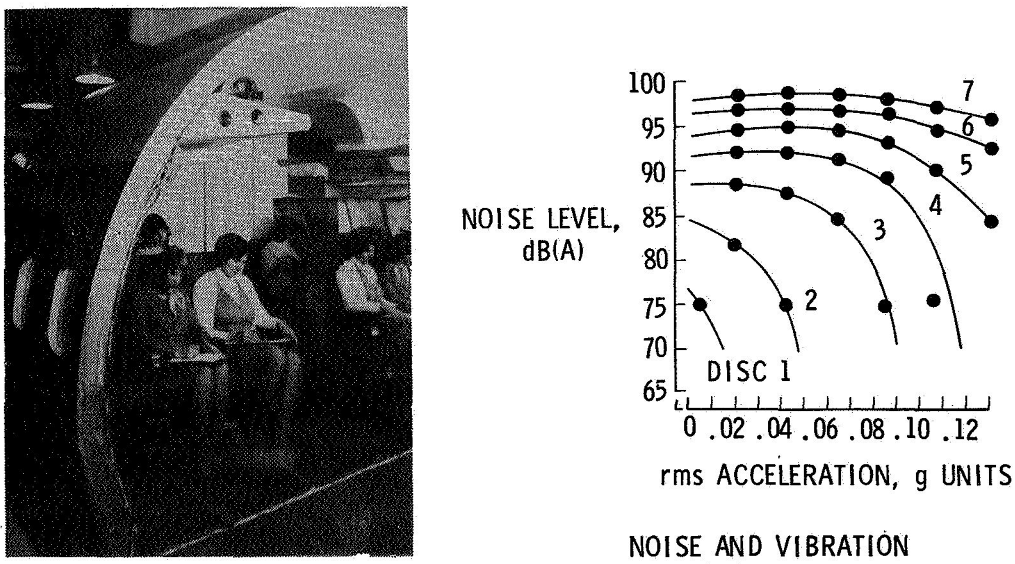


(c) Plan for field test of blade slap.



(d) Subject locations for field test of blade slap.

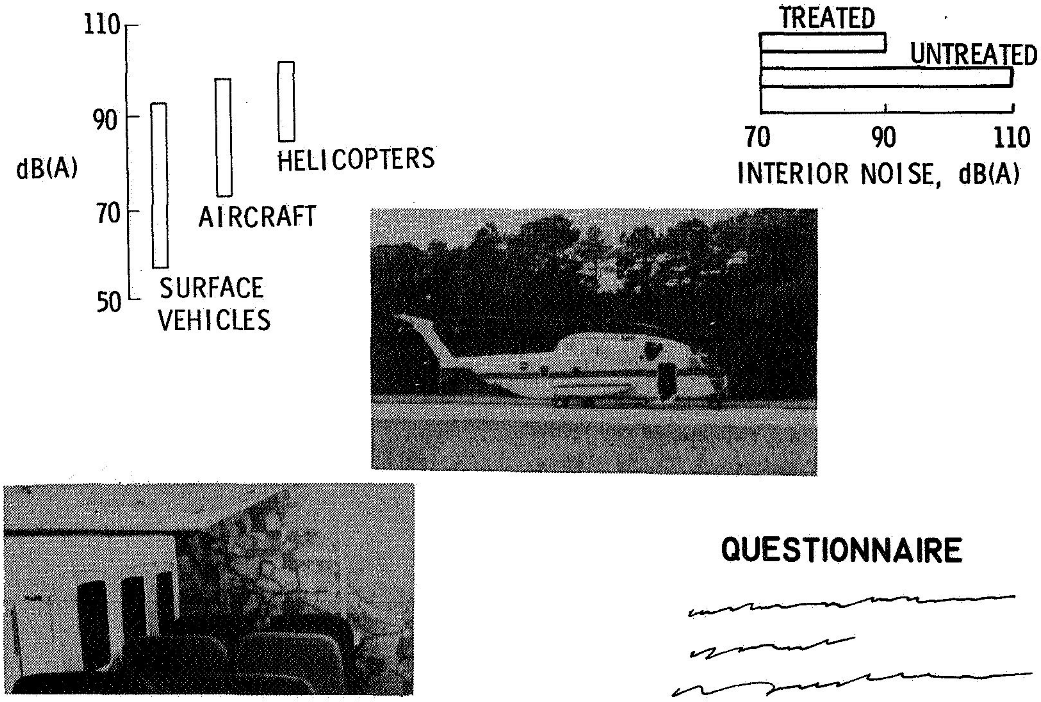
Figure 9.- Concluded.



PASSENGER RIDE QUALITY APPARATUS

NOISE AND VIBRATION CRITERIA

(a) Laboratory research.



(b) Field research.

Figure 10.- Passenger acceptance.